Universidade de Lisboa
Faculdade de Medicina Dentária

Fatigue Life of ProTaper Gold^{RM} Instruments

– An *in vitro* study –

Fátima Carolina Ferreira Pereira

Dissertação

Mestrado Integrado em Medicina Dentária

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Dissertação orientada pelo Prof. Doutor António Ginjeira e co-orientada pelo Prof. Doutor Rui Martins (FCT-UNL/DEMI)

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“Reconhecer a verdade como verdade, e ao mesmo tempo como erro; viver os contrários, não os aceitando; sentir tudo de todas as maneiras, e não ser nada, no fim, senão o entendimento de tudo.”

Fernando Pessoa

-

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RESUMO

Introdução: Endodontia é o ramo da Medicina Dentária que abrange o estudo, em particular, da polpa dentária assim como da raiz e dos tecidos periapicais. O tratamento de canais tem por objetivo preservar o dente, funcionalmente, facilitando a resolução da inflamação canalar e periapical. Este tipo de tratamento compreende vários passos, de componente química e mecânica, que envolvem a remoção do tecido pulpar e desinfeção do sistema canalar. A preparação mecânica, por sua vez, e através da utilização de vários instrumentos (manuais ou mecânicos) promove a desinfeção e *shaping* dos canais radiculares.

No entanto, a presença de uma anatomia canalar complexa e limitações inerentes aos próprios instrumentos utilizados no tratamento podem revelar-se um desafio. Desta forma, vários sistemas de instrumentos foram desenvolvidos, com diferentes propriedades mecânicas que os distinguem.

Recentemente, instrumentos fabricados a partir de ligas de Níquel-Titânio (NiTi) com resistência à fadiga consideravelmente superior e com *design* inovador, permitem um alargamento de canais radiculares curvos de forma mais eficaz e segura, preservando a anatomia.

Uma vez que a popularidade destes instrumentos é crescente, uma maior preocupação com a possibilidade de fratura durante a instrumentação está latente. Dois mecanismos de fratura estão largamente descritos na literatura: a fratura por fadiga e a fratura por torção. A fratura por fadiga ocorre quando um instrumento gira livremente num canal, gerando ciclos de tensão/compressão no ponto de máxima curvatura, até que a fratura ocorra. Esta, parece ser a maior causa de fratura nos instrumentos rotatórios endodônticos e pode ser avaliada através do Número de Ciclos à Fratura (NCF), dado pelo número de ciclos necessários até à fratura do instrumento.

Diversos fatores como o tipo de liga metálica, tratamento de superfície, secção de corte e dimensões do instrumento afetam a flexibilidade e NCF de diferentes limas. Deste modo, várias estratégias têm sido utilizadas de forma a aumentar a sua resistência, no culminar de diferentes sistemas de instrumentos rotativos.

Um dos sistemas de instrumentos NiTi rotatórios mais descrito é o sistema ProTaper® Universal (PTU) (Dentsply Maillefer, CH). Com uma conicidade progressiva ao longo do seu comprimento, secção triangular, centro de rotação coincidente com o centro de massa e ponta inativa, a sequência básica de instrumentação compreende a

utilização de 6 instrumentos: 3 para preparar o terço médio e coronal (SX, S1 e S2) e outros 3 para alargar o terço apical do canal (F1, F2 e F3).

O sistema ProTaper Next^{TM} (PTN) (Dentsply Tulsa Dental, OK, USA) foi lançado em Abril de 2013, com algumas características diferenciadoras, das quais: percentagem de conicidade progressiva, tecnologia M-*Wire*® e configuração *off-set*. Com secção rectângular e centro de massa não coincidente com o centro de rotação, este sistema é composto por 5 instrumentos: X1, X2, X3, X4 e X5.

Recentemente foi introduzido no mercado o sistema ProTaper Gold^{RM} (PTG) (Dentsply Tulsa Dental Specialities). A sua configuração geométrica compreende os mesmos princípios que o sistema PTU, assim como o mesmo número, tipo de instrumento e indicações de uso. No entanto, um tratamento de superfície com tecnologia CM-*Wire*® parece diferenciar este sistema, além de um comprimento de cabo 2 milímetros menor, que promete uma acessibilidade mais fácil ao dente. No entanto, a relação entre o tratamento de superfície e as propriedades de fadiga deste sistema têm pouca pesquisa independente disponível.

Materiais e Métodos: Foram analisadas 48 limas endodônticas, novas e sem utilização prévia, de 25 mm, do sistema PTG e PTU. 4 Grupos experimentais foram formados, de acordo com o tipo de sistema e lima utilizados – PTG F2 (n=12), PTG F3 (n=13), PTU F2 (n=12) ou PTU (n=12).

No seguimento dos estudos que têm vindo a ser desenvolvidos no âmbito da colaboração estabelecida entre o Departamento de Endodontia da Faculdade de Medicina Dentária da Universidade de Lisboa e o Departamento de Engenharia Mecânica da Faculdade de Ciências e Tecnologias da Universidade Nova de Lisboa, foi criado um sistema mecânico em que os instrumentos foram submetidos a forças que mimetizam um canal radicular. O raio de curvatura estabelecido foi de 4,7 mm e o ângulo de curvatura de 45˚. Cada instrumento foi inserido no contra-ângulo acoplado ao micromotor WaveOne^{TM} e submetido ao teste de fadiga com uma velocidade de rotação de 300 rpm e um binário de 4 N. cm. O tempo que a lima demorou a fraturar, foi registado com um cronómetro digital, sempre pelo mesmo operador. De seguida, o NCF foi calculado pela multiplicação da velocidade de rotação pelo tempo decorrido até à fratura.

A nível da análise estatística, os dados obtidos em relação ao tempo e NCF foram analisados pelo teste paramétrico de variáveis independentes de *t-student*, uma vez que a amostra apresentou uma distribuição normal. Por outro lado, os dados relacionados com o comprimento de fratura foram estatisticamente analisados pelo teste não paramétrico de U Mann-Whitney, uma vez que a amostra não apresentava normalidade.

De forma a comparar a média de tempo de fratura com os dados relativos ao estudo de Vaz 2014, um estudo *in vitro* que analisa o sistema PTN, o mesmo procedimento foi utilizado.

Resultados: Considerando as hipóteses, conclui-se: a média de NCF entre o grupo 1 – PTG F2 e o grupo 2 – PTG F3 é estatisticamente superior para o grupo 1 com um valor de p <0,001. Além disso, o valor de NCF para o grupo 3 – PTU F2 em relação ao grupo 4 – PTU F3 foi estatisticamente superior (p <0,001).

O local de fratura não mostrou, estatisticamente, ser significativamente diferente de acordo com o tipo de instrumento, entre os grupos 1 e 2, 1 e 3 e ainda entre os grupos 3 e 4. O mesmo não se verifica entre os grupos 2 e 4, sendo o comprimento de fratura estatisticamente superior para o grupo 4 (p <0,014).

O tempo até a fratura ocorrer entre os grupos 1 e 3, foi estatisticamente superior para o grupo 1, com valor p <0,001. O mesmo ocorre para o grupo 2 quando comparado com o grupo 4 (p <0,001).

Quando os dados entre as PTG e as PTN foram comparados, foi notado um tempo para a fratura estatisticamente superior para o grupo 1, em relação ao presente na amostra de PTN X2 (p <0,001). No entanto, o tempo até a fratura da amostra de PTN X3 foi estatisticamente superior à do grupo 2.

Discussão e Conclusões: Os instrumentos PTG F2 provaram ser significativamente mais resistente à fadiga que os instrumentos PTG F3. O mesmo pode ser afirmado para a amostra de PTU F2 em relação com a amostra de PTU F3. Estes resultados parecem estar relacionados com o aumento no diâmetro que se verifica entre os instrumentos F2 e F3.

Além disso, as amostras de PTG F2 e PTG F3 provaram ser estatisticamente superiores, no que toca ao tempo para a fratura, que as PTU F2 e PTU F3, respetivamente. Esta análise está de acordo com o observado em estudos prévios e a razão parece estar relacionada com a tecnologia CM-*Wire*® utilizada no fabrico dos instrumentos PTG.

Por outro lado, a média para o comprimento de fratura entre as PTG F2 e as PTG F3 e para as PTG F2 em relação com as PTU F2 não foi significativa. É referido na literatura que a fratura ocorre normalmente no ponto de máxima curvatura, no entanto houve uma diferença estatisticamente significativa entre os instrumentos PTG F3 e PTU F3. Esta diferença pode dever-se a vieses inerentes ao próprio estudo, sendo a tomada de conclusões complexa.

Dados referentes ao estudo feito por Vaz 2014, que analisou 24 limas do sistema PTN sob o mesmo sistema mecânico e procedimento que o presente estudo, revelaram que o tempo médio para a fratura das PTG F2 foi superior ao observado para as PTN X2, e que as PTN X2, por sua vez, têm um valor médio superior às PTU F2. Isto pode dever-se a diferentes composições metálicas entre os instrumentos, para além de diferenças a nível de secção de corte e tratamento de superfície. Por um lado, instrumentos construídos com CM-*Wire*® têm uma maior resistência à fadiga em relação a outros instrumentos, segundo estudos recentemente desenvolvidos. Por outro, foi demonstrado que uma secção triangular é compatível com melhores resultados de resistência à fadiga entre instrumentos.

Além dos resultados obtidos através da análise estatística das amostras, comparam-se os dados com estudos referentes ao mesmo sistema, onde denotaram-se valores para a resistência à fadiga muito variáveis. Estas variações parecem estar relacionadas com diferenças a nível do ângulo e raio de curvatura dos canais utilizados, assim como diferenças a nível ambiente experimental.

Posto isto, conclui-se que o sistema ProTaper Gold^{RM} parece apresentar uma resistência à fadiga superior em relação a sistemas previamente desenvolvidos, sendo um sistema a inserir no leque de opções válidas para utilização clínica. Além disso, há urgência em criarem-se padrões específicos e internacionais para testar a resistência à fadiga de instrumentos rotatórios. O mesmo pode ser referido no que toca ao método mais preciso para a análise estatística correspondente, de forma a atingir uma comparação de evidência científica superior.

Palavras-chave: ProTaper Gold; Resistência à Fadiga, Instrumentos Níquel-Titânio; Instrumentação Mecanizada; Endodontia.

ABSTRACK

Introduction: Nickel-titanium instruments were introduced to facilitate canal preparation. Despite its advantages, instrument separation remains a major concern in endodontics due to several factors. There are many systems of endodontic files and the purpose of this study was to characterize the cyclic fatigue of ProTaper Gold^{RM} (PTG) instruments and compare it to Protaper® Universal (PTU) and other rotary systems.

Materials and Methods: Forty-eight rotary nickel-titanium files of PTG and PTU systems were analyzed in this study. Those were divided into four experimental groups, according to type of system and instrument (PTG F2, PTG F2, PTG F3, PTU F2 and PTU F3). A mechanical device was used to simulate the root canal system with a radius of curvature of 4, 7 mm and an angle of curvature of 45˚. Each instrument was submitted to testing with rotational speed of 300 rpm and a torque of 4 N. cm. Testing time was registered when tip separation occurred. Data obtained such as time to fracture of the instrument tested and number of cycles to fracture (NCF) was statically analyzed by *t*-student test. For fracture length the non-parametric U-Whitman test was used. PTG and ProTaper Next™ (PTN) data from Vaz 2014 study were analyzed with the same tests. Significance was set at 95% confidence level.

Results: PTG F2 instrument proved to be statistically more resistant to cyclic fatigue than instruments PTG F3, PTU F2 and PTN X2.

Discussion and Conclusions: Compared with different rotary systems such as PTU and PTN, this system suggests being more resistant to cyclic fatigue. During clinical practice, clinicians should be aware of the mechanical properties of the instruments chosen and take into account the higher resistance to cyclic fatigue of ProTaper Gold^{RM} files when compared to other systems.

Key-words: ProTaper Gold; Cyclic Fatigue; Nickel-titanium Instruments; Rotary Preparation; Endodontics.

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I. Introduction

Endodontics is the branch of dentistry, concerned with morphology, physiology, and pathology of the human tooth, and in particular the dental pulp, root and peri-radicular tissues (Wu & Wesselink 1993).

Pulp disease is usually inflammation of connective tissue (the pulp), which can be caused by any type of injury (mechanical, physical, chemical, thermal or electrical) (European Society of Endodontology 2006).

Treatment aimed at preserving a functional pulp by facilitating resolution of pulp inflammation is called vital pulp therapy. Treatment aimed at preserving a functional tooth by facilitating resolution of periapical inflammation is called root canal treatment (Gulabilava & Ng 2014).

Root canal treatment involves the removal of pulpal tissue and the disinfection of the root canal system, by series of steps (mechanical and chemical). Mechanical preparation using a variety of instruments (both manual and machine driven) promotes cleaning and shaping, in which the ideal prepared root canal shape is a three-dimensional continuously tapering cone, narrowest apically and widest at the root canal entrance, always respecting the root anatomy.

However, some challenges can be found during root canal preparation, like complex anatomy of the root canal system and instrumental limitations inherent to treatment (Gulabilava & Ng 2014; Patel & Barne 2013).

A. Type of Instruments

Endodontic instruments for root canal preparation can be divided into three groups:

1. **Hand-and finger-operated instruments.**
2. **Low-speed instruments.**
3. **Engine-driven instruments.**

Historically most instruments used were designed to be used by hand. Although not universally used, rotary instrumentation has gained considerable interest and can enhance the quality of treatment (Cohen & Hargreaves 2006).

B. Instrument composition

1. Stainless Steal

At first, root canal instruments were manufactured from carbon steel. However, chemicals (e.g. iodine, chorine) and steam sterilization caused significant corrosion. Subsequently, the use of stainless steel greatly improved the quality of instruments (Wu & Wesselink 1993).

Still, the high stiffness value of typical steel – the property of a solid body to resist deformation – remained as the great disadvantage of these instruments. This feature produced forces in the anti-curvature wall causing wear and modification of the original root canal shape during instrumentation. Consequently the prognosis could be worst due to non-successful instrumentation (Plotino *et al*. 2009).

2. Nickel-Titanium

More recently, Nickel-Titanium (NiTi) alloys represented a major breakthrough in Endodontics, overcoming the high stiffness of instruments made of stainless steel.

With considerably higher fatigue resistance than stainless steel instruments of similar size, together with innovative file designs, a more effective and safer enlargement of curved canals, without significantly losing their original path, is possible and at a much faster rate than hand files. (Tripi *et al*. 2006; Lopes *et al*. 2009; Lee *et al*. 2011)

- **NiTi structure**

The NiTi alloys used in endodontic instruments are generically called **55-Nitinol**, which contain approximately 56% nickel and 44% titanium. The resultant combination is a one-to-one atomic ratio (equiatomic) of the major components.

The crystalline structure of NiTi alloy at high temperature ranges (≥100˚C) is a stable, face-centered cubic lattice which is referred to as the **Austenite Phase or Parent Phase** (Fig.1).

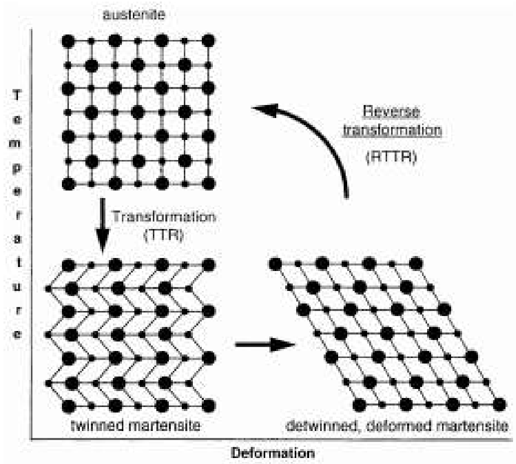


Figure 1 - Diagramatic representation of the martensitic transformation and shape memory effect of NiTi alloy (Thompson 2000).

When it is cooled through a critical transformation temperature range (TTR), there is a change in the crystal structure which is known as the martensitic transformation that originates the so called **Martensitic or Daughter Phase** (Fig 1). The martensite shape can be deformed easily to a single orientation by process known as **de-twinning**.

The transition from the austenitic to martensitic phase can also occur as a result of application of stress, such occurs during root canal preparation. This stress-induced martensitic (SIM) transformation is reversible; hence the material exhibits an unusually large elastic range and is able to recover from a much higher strain than stainless steel can withstand without breaking (Hou *et al*. 2010; Shen *et al*. 2011; Tsujimoto *et al*. 2014).

It is the crystalline change phenomenon described earlier which gives rise to the **shape memory effect** of the material and the **superelastic behavior** (Kauffman & Mayo 1997; Thompson 2000; Stojanac *et al*. 2012).

Hereupon, during the last decade NiTi rotary instruments have been gaining popularity among almost all dentists practicing endodontic therapy. However, visible inspections is not a reliable method for the evaluation of the physical integrity of NiTi instruments, therefore an increasing concern about instrument fracture during clinical procedure is present (Lopes *et al*. 2009; Lee *et al*. 2011).

C. When fracture occurs

Two distinct fracture mechanisms have been identified, namely due to: fatigue crack propagation (cyclic fatigue fracture) and due to torsional failure.

- **Torsional failure** occurs when an instrument tip or another part of the instrument is locked in a canal while the shank continues to rotate.
- **Cyclic fatigue fracture**, in which the instrument rotates freely inside a curvature canal, generating tension/compression cycles at the point of maximum bending until fracture occurs. This type of fracture is due to metal fatigue and is usually localized at the point of maximum curvature (Li *et al*. 2002; Plotino *et al*. 2009; Wan *et al*. 2011; Lee *et al*. 2011; Lopes *et al*. 2011; Bouska *et al*. 2012).

According to Cheung *et al*. the great majority (93%) of instruments appeared to have failed due to cyclic fatigue. This might be explained as follows: fatigue-crack growth rates in NiTi alloys have been reported to be significantly greater than in other metals of similar strength. Thus, once a micro-crack is initiated, it can quickly propagate to cause catastrophic failure (Stojanac *et al*. 2012).

Therefore, understanding cyclic fatigue resistance of different endodontic instruments may be a subject of interest and different tests for cyclic fatigue emerged.

1. Cyclic Fatigue Testing

The **fatigue life** of a material is the number of fatigue cycles required to its failure. The cyclic fatigue tests are a simple and reliable approach to determine the fatigue behavior of instruments manufactured from the NiTi alloy (Tripi *et al*. 2006).

Since the number of cycles until failure is cumulative, it can be obtained through the multiplication of the rotation speed by the time elapsed until fracture occurs (Lopes *et al*. 2009).

The devices used to determine the fatigue resistance of endodontic instruments, allow instruments to rotate until fracture using different geometric curvatures (Plotino *et al*. 2009).

Rotational bending fatigue tests can also be carried out with or without the axial movement of the endodontic instrument. In static tests, the instrument rotates, with no axial displacement, whereas in the dynamic model the instrument is moved back and forth within the canal (Rodrigues *et al*. 2011).

Earlier cyclic fatigue studies have noticed the influence of canal shape on instruments breakage. Canal curvature can be expressed by the radius of curvature and the angle of curvature as seen in Figure 2 (Pruett *et al*. 1997).

- The **radius of curvature** is the radius of the circle that approaches the curvature of the canal most tightly – the radius of the osculating circle.
- The **angle of curvature** is the angle between two radii of the osculating circle intersecting the end points of the canal curvature.

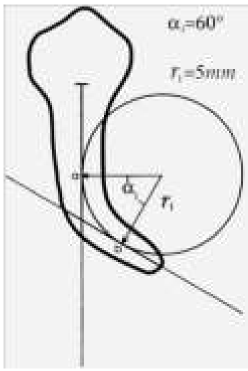


Figure 2 - Pruett's method for describing canal geometry using two parameters: radius of curvature and angle of curvature (Pruett *et al*. 1997).

The variation of both the angle and the radius of curvature of a canal will induce different stresses on an instrument, thereby extending or reducing its fatigue life (Wan *et al*. 2011).

To date, there is no specification or international standard to define cyclic fatigue resistance of endodontic rotary instruments. As a result, several devices and methods have been used to investigate *in vitro* cyclic fatigue failure (Plotino *et al*. 2009).

D. Improving performance

Some factors, including the type of metal alloy, impurities, heat treatments, number of threads, helical angle, cross-sectional shape and dimensions affect the flexibility and cyclic lifespan of files (Parashos *et al*. 2006; Gutman & Gao 2011; Lee *et al*. 2011; Shen *et al*. 201;, Versluis *et al*. 2012; Uygun *et al*. 2015).

Hence, strategies have been used to improve the fatigue resistance of NiTi endodontic instruments. Recently, thermal treatment of NiTi alloys, e.g. Controlled Memory wire (CM-Wire®) (DS Dental, Johnson City, TN), Memory wire (M-Wire®) (Dentsply Tulsa Dental Speacialities, Tulsa, OK), and R-phase wire (SybronEndo, Orange, CA) has been used. (Gutman & Gao, 2011; Condorelli *et al*. 2010; Shen *et al*. 2011; Pérez-Higueras *et al*. 2014; Hiewy *et al*. 2015; Capar *et al*. 2015).

That way, several NiTi file systems are currently available with differentiating characteristics that may attribute clinical advantages (Tripi *et al*. 2006; Larsen *et al*. 2009).

1. ProTaper® Universal

ProTaper® Universal (PTU) (Dentsply Maillefer, CH) is a well-described NiTi rotary system of instruments manufactured with progressive taper over the length of the cutting blades, triangular cross-sections, and non-cutting tips (Hiewy *et al*. 2015).

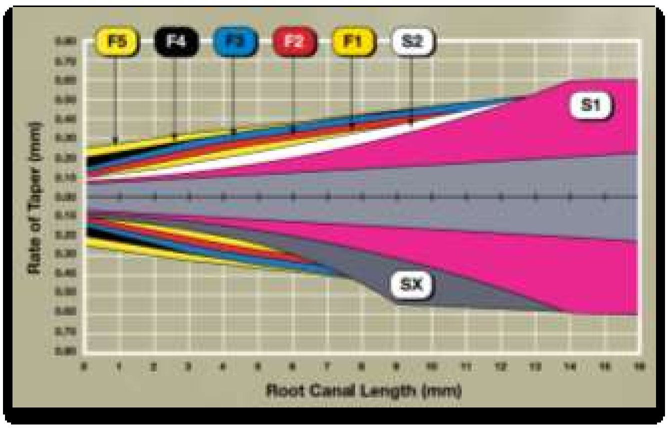


Figure 3 - Rate of taper: the rate of taper varies along the cutting flutes of each ProTaper® Universal file (Dentsply Maillefer).

The basic sequence to shape root canals with PTU includes 6 instruments, 3 of them to prepare the coronal and middle third (SX, S1 and S2) and the other 3 to enlarge the apical third (F1,F2 and F3), (Fig. 4) (Pérez-Higueras *et al*. 2015).

Figure 4 - Protaper® Universal system composed by shaping and finishing files (Dentsply Maillefer).

Shaping files pre-enlarge and shape the coronal 2/3 of the canal with brushing movements. Finishing files finish the apical 1/3 and only can be used until they reach the full working length, no brushing movements. These files have, in sequence, purple (S1), white (S2), yellow (F1), red (F2, blue (F3), double black (F4) and double yellow (F5) identification rings corresponding to sizes 18/02, 20/04, 20/07, 25/08, 30/09, 40/06 and 50/05.

There's also available SX shaper file, used only with the purpose of improving canal access, size 19/04.

SX, S1, S2, F1 and F2 have a convex triangular cross section that is responsible for giving them resistance. F3, F4 and F5, present a different section, with concave triangular cross sections, giving them flexibility (Fig. 5).

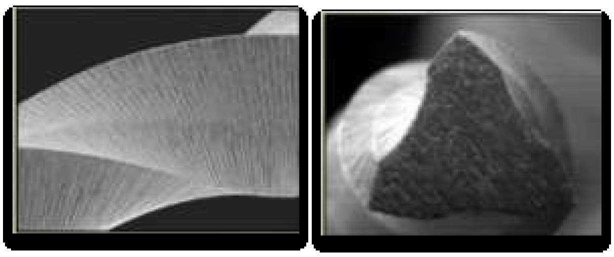


Figure 5 – ProTaper® Universal F3, F4 and F5 finishing files feature a reduced cross section. A convex, triangular cross section reduces contact with canal wall (Dentsply Maillefer).

These files are available in 3 lengths, 21, 25 and 31 mm, and have a rotation center coincing with their mass center (Ruddle 2008; Hiewy *et al*. 2015; Dentsply Maillefer).

2. Protaper Next^{TM}

The Protaper Next^{TM} rotary file system (PTN) (Dentsply Tulsa Dental, OK, USA) had its market debut on April 2013 and, according to the manufacturers, these files are the convergence of three significant design features: progressive percentage tapers on a single file, **M-Wire® technology** and off-set configuration.

The rectangular cross section along with the non-coincidence between the rotation center and the mass center of the file, results in a limited contact of the cutting blades with the dentin wall, where only two points of the rectangular cross section are responsible for cutting.

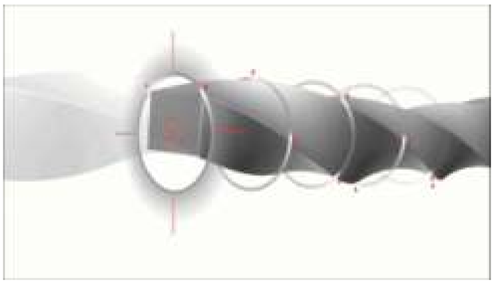


Figure 6 – ProTaper Next^{TM} rectangular cross section (Dentsply Tulsa Dental).

This system is composed by five files, X1,X2, X3, X4 and X5, all in different lengths (21,25 and 31 mm). In sequence, yellow, red, blue, double black and double yellow identification rings corresponds to sizes 17/04, 25/06, 30/07, 40/06 and 50/06 respectively (Pérez-Higueras *et al*. 2015; Dentsply Maillefer).

Figure 7 – ProTaper Next^{TM} X1, X2, X3, X4 and X5 instruments (Dentsply Tulsa Dental).

3. Protaper Gold^{RM}

ProTaper Gold^{RM} (PTG), (Dentsply Tulsa Dental Specialties) instruments were introduced recently in the US market. These files have a design that features identical geometries as ProTaper® Universal, as well as the same instruments set and manufacturer's instructions for usage. Still, there is a differentiating heat-treatment with the newest **CM-Wire® technology** (Hiewy *et al*. 2015; Uygun *et al*. 2015).

The full set of files is represent in Figure 8 and it is composed, as well, by two shaping files, S1 and S2 and 5 finishing files, F1,F2,F3, F4 and F5.

Figure 8 – ProTaper Gold^{RM} system composed by shaping and finishing files (Dentsply Tulsa Dental Specialties).

However, this system shows a different size of the handle, having eleven millimeters compared to the thirteen from ProTaper® Universal system. According to the manufacturer, this smaller handle allows improved accessibility to the tooth.

Hence, a different **phase transformation behavior** determines advanced metallurgical and mechanical, resulting in improved flexibility and fatigue life. Yet, the relationship between thermal behavior and fatigue properties of new PTG endodontic instruments has not been investigated (Hiewy *et al*. 2015; Uygun *et al*. 2015).

II. Aims

The main aim of this *in vitro* study is to analyze the Fatigue Life of the recently developed ProTaper Gold^{RM} NiTi instruments since little independent research is available.

Beyond that, once manufacturers proclaim that this system has improved flexibility and higher cyclic fatigue over ProTaper® Universal, other purpose of this study is to examine the fatigue life of PTG system and compare it with its predecessor and other ProTaper® in order to take further clinical decisions.

A. <u>Specific goals</u>

- To compare the fatigue life of instruments F2 and F3 of ProTaper Gold^{RM} system.

H0 – The number of cycles until break is alike in both instruments.
H1 – The number of cycles until break is different in both instruments.

- To compare the length of fracture in instruments F2 and F3 of ProTaper Gold^{RM} system.

H0 – The length of fracture is alike in both instruments.
H1 – The length of fracture is different in both instruments.

- To compare the fatigue life of F2 instruments of ProTaper Gold^{RM} with F2 instruments of ProTaper® Universal.

H0 –Time to fracture is alike in both instruments.
H1 – Time to fracture is higher for PTG.
H2 –Time to fracture is higher for PTU.

- To compare the fatigue life of F3 instruments of ProTaper Gold^{RM} with F3 instruments of ProTaper® Universal.

H0 –Time until break is alike in both instruments.
H1 – Time until break is higher for PTG.
H2 –Time until break is higher for PTU.

- To compare the fatigue life of F2 instruments of ProTaper Gold^RM with X2 instruments of ProTaper Next^TM.

H0 –Time to fracture is alike in both instruments

H1 - Time to fracture is higher for PTG F2.

H2 –Time to fracture is higher for PTN X2.

- To compare the fatigue life of F3 instruments of ProTaper Gold^RM with X3 instruments of ProTaper Next^TM.

H0 –Time to fracture is alike in both instruments.

H1 - Time to fracture is higher for PTG F3.

H2 – Time to fracture is higher for PTN X3.

B. Main Goals

Through a bibliographic review, to compare the fatigue life of ProTaper Gold^RM instruments data with other studies.

III. Materials and Methods

A. <u>Instruments</u>

For this *in vitro* study two types of variable taper rotary files from ProTaper Gold^{RM} and ProTaper® Universal systems were used.

Those constituted four experimental groups, as seen in Table 1.

	Group	Type of file	n	Length (mm)	Taper
Experimental Groups	1	PTG F2	12	25	0,08
	2	PTG F3	12	25	0,09
	3	PTU F2	12	25	0,08
	4	PTU F3	12	25	0,09

Table 1– Samples distributed through the experimental groups with respective length (mm) and taper.

Group 1 and group 3 had red identification rings on their handles corresponding to D0 diameters of 0.25 mm, fixed tapers between D1 and D3 of 0,08 and "decreasing" tapers from D14-D14. Group 2 and group 4 had blue identification rings with D0 diameter of 0,30 mm, fixed tapers between D1 and D3 of 0,09, and "decreasing" tapers from D14-D14 as well (Ruddle 2008).

The samples used during experimental fatigue testes were sterilized and new, without any previous utilization. Manufacturer DENTSPLY had no influence in the present study (Fig. 9).

Figure 9 – Samples used for the *in vitro* study.

B. <u>Equipment</u>

In order to carry out the fatigue tests, a mechanical system was developed by Alexandre and Pinto in 2013 through a partnership between the Endodontics Department of Faculdade de Medicina Dentária da Universidade de Lisboa and the Mechanical and Industrial Engineering Department of Faculdade de Ciências e Tecnologias da Universidade de Lisboa (Pinto 2013). The drawings, dimensions and prototype can be seen in Figure 10.

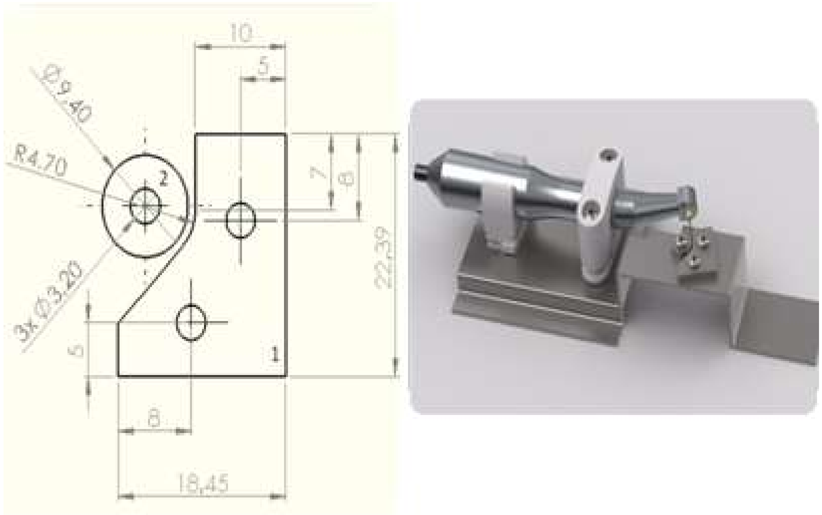


Figure 10 - (a): Test bench with general measures (Pinto 2013). (b): System prototype (Fernandes 2013).

This system was constituted by 2 pieces, 1 and 2, which articulate in order to mimic one vertical root canal with a curvature angle of 45º and a radius of curvature equal to 4, 7 mm.

Piece number 1 was manufactured by a Computerized Numerical Control machine (CNC). Piece number 2 was manufactured from a rod of stainless steel machined and hole-drilled. The stand structure was manufactured from a stainless steel plate with 1,5mm thick with several folding, cutting and welding.

A point with specific coordinates was set: (4,026; 9,026) (Fig. 11). This point establishes the place where the tip of the instrument should be in each test and had a distance of 5 mm from the beginning of the curvature of the simulated root canal.

The configuration of the device and the location of W point are represented in Figure 9. The instrument enters the mechanical system in (a), it's forced to bend and adjust to the curvature in (b) and its tip is visible in (c).

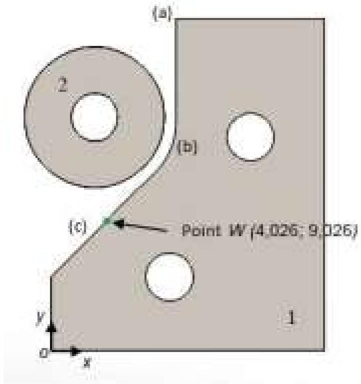


Figure 11 - Schematic representation of the mechanical system adapted from Pinto 2013.

As seen in Figure 12 (a), three bolts prevented the different pieces to move apart so all system was static with the exception of the instrument tested. A malleable screen of Teflon supported the device, which was fixed with two staples.

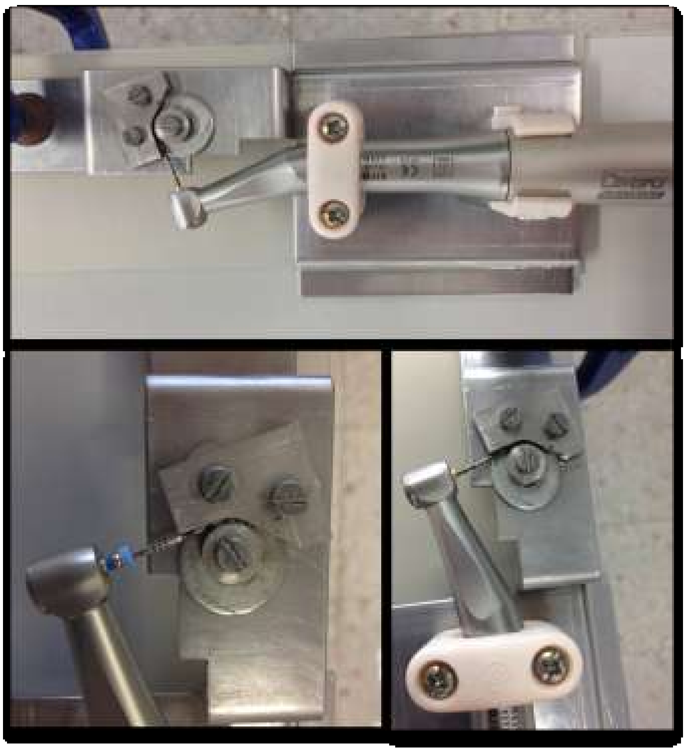


Figure 12 – (a): Mechanical System with the three bolts used to prevent the different pieces to move apart and malleable screen of Teflon supporting the device. (b): PTG F3 during CF testing. (c): PTU F3 during cyclic fatigue testing.

The motor used was a WaveOne^{TM} (Dentsply Maillefer), set at the ProTaper Universal programme, with 300 rpm of continuous rotary motion and a torque of 4 N. cm, following manufacturer's recommendations.

One visible difference between PTG and PTU is the different size of the handle, being smaller - 2 millimeters less - in this new system. Therefore, some modifications were needed and made in the support structure, in order to adjust the tip of the file to the W point. With a drilling engine, the original holes were extended, allowing the PTG file to adjust, not falling short in the simulated root canal (Fig. 13).

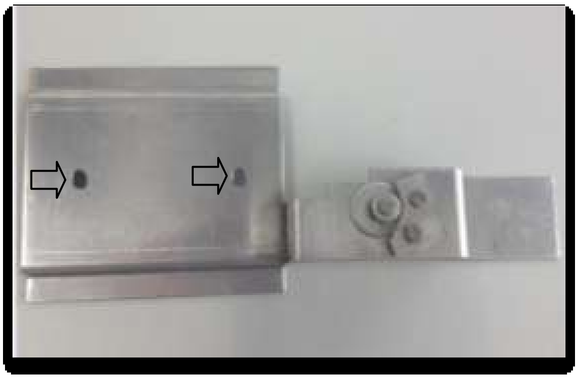


Figure 13 – Support structure with extended holes.

All parameters guaranteed equal experimental conditions ensuring reproducibility of the experiment.

C. Experimental procedure

The same methodology was used to test all instruments, on which the same operator was responsible for the fulfillment of required steps. The procedure comprehended the following steps:

1) Place the motor in the fixed system;
2) Place the instrument to be tested in the contra-angle and rotate the head of the contra-angle until the instrument is parallel to the bench;
3) Make sure that the instrument is between pieces no. 1 and 2;

4) Adjust the instrument ensuring that it's perpendicular to the upper part of the block, the instrument is well adjusted between the two pieces and the extremity of the file is well positioned at the W point (Fig. 12);
5) Tighten the three bolts and nuts according to the previous adjustments;
6) Turn on the WaveOneTM motor equipment and select the ProTaper Universal programme;
7) Get the chronometer set up and ready to be use;
8) Step on the pedal initiating the chronometer at the same time, until separation of the instrument occurs;
9) Stop the chronometer when the tip of the instrument comes off;
10) Remove the instrument off the contra-angle and measure the length of the instrument with a ruler;
11) Repeat every step for all instruments.

The time each file took until fracture (*t*), was registered with a digital chronometer. Time started at the beginning of the test and stopped at the moment the operator detected instrument separation by observing and/or hearing the displacement of the tip protruding from the artificial canal.

Since rotational speed employed in the fatigue test device was 300 rpm, the NCF was determined by the following formula:

$$\text{NCF} = \frac{300t}{60} \leftrightarrow 5t \qquad t\text{, in seconds}$$

The fracture point in relation to the tip of the instrument was measured for each experiment.

D. <u>Statistical analysis</u>

IBM® SPSS® Statistics version 22.0.0 Software was used to carry out the statistical analysis, on which initially a descriptive analyses was performed. For each experimental group the mean, the standard deviation and the variance were calculated.

Subsequently, the Kolmogorov-Smirnov test was used to evaluate the data obtained on time to fracture (sec), fracture length (mm) and Number of Cycles to Fracture (NCF) for normal distribution.

Time to fracture and NCF revealed a normal distribution for all groups (K-S>0, 05). Thus, the analysis through the *t*-student test for independent samples was used in order to clarify the correct hypotheses.

On the other hand, data for length of fracture was statically analyzed by a non-parametric test, U Mann-Whitney for independent samples, since the data had no normality for the distribution of group 1 and group 4 (K-S<0, 05).

Beyond that, data for mean time to fracture for group 1 and group 2 was compared with data of ProTaper Next^{TM} X2 and X3 present in Vaz 2014 study, respectively. Mean time to fracture between group 3 and X2 was also analyzed.

Since X2 data showed no normality (K-S<0,05), the U Mann-Whitney for independent samples was used to analyze the mean times to fracture of group 1 and group 3 with PTN X2. In the other hand, X3 data showed a normal distribution, so the *t*-student test for independent samples was applied in order to compare the mean times to fracture of group 2 with PTN X3.

The significance was set at 95% confidence level and differences were considered statistically significant when *p*<0, 05.

IV. Results

Data obtained during the experimental tests regarding time to fracture, fracture length and NCF for each type of file are presented in Table 2 (group 1 and group 2) and Table 3 (group 3 and group 4).

Group	Type of file	Time to fracture (sec)	Fracture length (mm)	NCF
1	$F2_1$	102,17	6,5	510,85
	$F2_2$	114,07	6	570,35
	$F2_3$	127,21	6,5	636,05
	$F2_4$	52,5	8	262,5
	$F2_5$	112,91	6,5	564,55
	$F2_6$	113,01	6,5	565,05
	$F2_7$	107,09	5	535,45
	$F2_8$	139,28	6,5	696,4
	$F2_9$	108,61	6,5	543,05
	$F2_{10}$	91,34	6,5	456,7
	$F2_{11}$	109,28	6	546,4
	$F2_{12}$	140,32	7	701,6
2	$F3_1$	20,01	6,5	102,5
	$F3_2$	42,4	6,5	210,2
	$F3_3$	70,85	6	354,25
	$F3_4$	52,87	7	264,35
	$F3_5$	41,19	7	205,95
	$F3_6$	82,35	7	411,75
	$F3_7$	70,11	6,5	350,55
	$F3_8$	64,63	6,5	323,15
	$F3_9$	57,29	6	286,45
	$F3_{10}$	66,79	6	333,95
	$F3_{11}$	78,39	6,5	391,95
	$F3_{12}$	59,7	6,5	298,5

Table 2 – Time to fracture, fracture length and NCF data from group 1 and 2 – ProTaper Gold^RM instruments.

Group	Type of file	Time to fracture (sec)	Fracture length (mm)	NCF
3	$F2_1$	57,37	5	286,85
	$F2_2$	62,8	5,5	314
	$F2_3$	55,63	6,5	278,15
	$F2_4$	63	7	315
	$F2_5$	39,06	6,5	195,3
	$F2_6$	61,21	7	306,05
	$F2_7$	58,56	7	292,8
	$F2_8$	60,1	7	300,5
	$F2_9$	61,21	7	306,05
	$F2_{10}$	58,56	6	245,8
	$F2_{11}$	60,01	5,5	286,45
	$F2_{12}$	54,97	7	274,85
4	$F3_1$	34,98	6	174,9
	$F3_2$	35,61	6	178,05
	$F3_3$	25,37	6,5	126,85
	$F3_4$	24,59	6,5	122,95
	$F3_5$	32,73	6	163,65
	$F3_6$	27,51	6,5	137,55
	$F3_7$	34,52	6	172,6
	$F3_8$	25,86	6	129,3
	$F3_9$	25,27	6	126,35
	$F3_{10}$	34,25	6	171,25
	$F3_{11}$	28,34	6	141,7
	$F3_{12}$	51,31	5,25	256,55

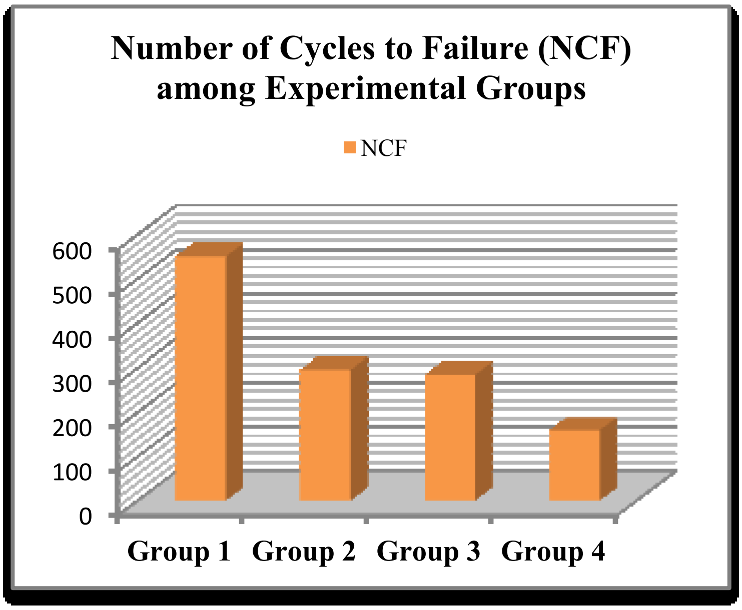
Table 3 – Time to fracture, fracture length and NCF data from group 3 and 4 – ProTaper® Universal instruments.

Descriptive statistics for the different experimental groups over time to fracture, fracture length and NCF are displayed in Table 4.

	Group	Type of file	Quantity	Mean ± St. Deviation	Variance
Time to fracture (sec)	1	PTG F2	12	109,82 ± 23,03	486,10
	2	PTG F3	12	58,18 ± 17,01	311,93
	3	PTU F2	12	56,70 ± 6,78	45,96
	4	PTU F3	12	31,70 ± 7,51	56,46
Length of fracture (mm)	1	PTG F2	12	6,46 ± 0,70	0,48
	2	PTG F3	12	6,5 ± 0,37	0,14
	3	PTU F2	12	6,42 ± 0,73	0,54
	4	PTU F3	12	6,06 ± 0,34	0,12
NCF	1	PTG F2	12	549,08 ± 115,14	13257,19
	2	PTG F3	12	294,46 ± 87,97	7749,38
	3	PTU F2	12	283,48 ± 33,90	1148,99
	4	PTU F3	12	158,48 ± 37,57	1411,44

Table 4 – Descriptive analysis: mean, standard deviation and variance regarding time, length of fracture and NCF.

An overview of the mean NCF for each group is present in Graphic 1 as well.



Graphic 1 – Graphical representation of NCF for group 1, 2, 3 and 4.

In order to compare ProTaper Gold^{RM} and ProTaper Next^{TM} systems, the data regarding PTN X2 and PTN X3 instruments for time to fracture from Vaz 2014 study was selected, since the corresponding instruments PTG F2/PTN X2 and PTG F3/PTN X3 are used for similar purposes during treatment (Dentsply Tulsa Dental brochure).

	Type of file	Quantity	Mean ± St. Deviation	Variance
Time to fracture (sec)	PTG F2	12	109,82 ± 23,03	486,10
	PTN X2	16	77,8 + 9,3	87,4
	PTG F3	12	58,18 ± 17,01	311,93
	PTN X3	4	89,3 + 9,5	89, 4

Table 5 – Mean time to fracture data from the present study and from Vaz 2014 study.

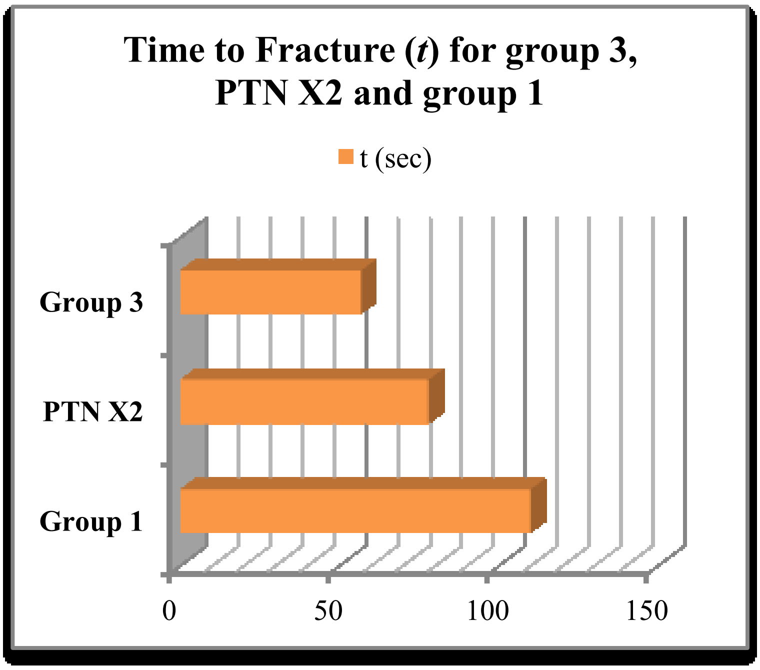
Through statistical analysis previously described and considering the initially formulated hypothesis, the following data were earned:

- The mean value of NCF between group 1 (549, 08 ± 115, 14) and group 2 (294, 46 ± 87, 97) was found to have a significant statistical difference, **rejecting the null hypothesis (H0)** (p <0.001).
- There was not found a significant statist difference concerning length of fracture among group 1 (6, 46 ± 0, 70) and group 2 (6, 5 ± 0, 37), **retaining the null hypothesis (H0)**.
- The mean value of time to fracture between group 1 (109, 82 ± 23, 03) and group 3 (56, 70 ± 6, 80) was found to have a significant statistical difference, **rejecting the null hypothesis (H0)** (p <0.001).
- The mean value of time to fracture between group 2 (58, 18 ± 17, 01) and group 4 (31, 70 ± 7, 51) was found to have a significant statistical difference, **rejecting the null hypothesis (H0)** (p <0.001).
- The mean value of time to fracture between group 1 (109, 82 ± 23, 03) and PTN X2 (77, 8 + 9, 3) was found to have a significant statistical difference, **rejecting the null hypothesis (H0)** (p <0.001).
- The mean value of time to fracture between group 2 (58, 18 ± 17, 01) and PTN X2 (77, 8 + 9, 3) was found to have a significant statistical difference, **rejecting the null hypothesis H0** (p=0,006).

<u>Beyond that, statistic analyses show</u>:

- The mean value of NCF between group 3 (283, 48 ± 33, 90) and group 4 (158, 48 ± 37, 57) was found to have a significant statistical difference (p <0.001).
- There was not found a significant statistical difference for mean time to fracture within group 2 (58, 18 ± 17, 01) and group 3 (56, 70 ± 6, 80).
- A significant statistical difference, concerning the mean values for length of fracture among group 2 (6, 5 ± 0, 37) and group 4 (6, 06 ± 0, 34) was found (p = 0, 014).

A graphical demonstration shows a visible difference among 3 groups of ProTaper® Universal, ProTaper Next™ and Protaper Gold^{RM} systems analyzed (Grap. 2).



Graphic 2 – Mean time to fracture (sec) for group 1 – PTG F2, PTN X2 and group 3 – PTU F2.

V. Discussion

In many cases, fracture of rotary NiTi instrument occurs because of incorrect or excessive use, which stresses the importance of correct training in the use of rotary NiTi technology. However, many factors have been linked to the propensity for fracture of rotary NiTi instruments (Parashos & Messer 2006).

The main aim for this *in vitro* study is to analyze the fatigue life of the new Protaper Gold^{RM} system. Moreover, since manufacturer proclaims that this system has improved flexibility and higher resistance to cyclic fatigue over ProTaper® Universal system, other purpose of this study is to compare it with its predecessor in order to take further clinical decisions.

Time to failure data (*t*) was recorded along the experimental procedure and NCF was determined afterwards. These two parameters have been used to assess cyclic fatigue resistance over time, in which *t* presents more clinically relevance information, as time is much easier for the operator to observe than the number of cycles the instrument endures. In addition, NCF offers more pertinent information regarding the ability of the instrument design to withstand cyclic fatigue (Wan *et al*. 2011).

- <u>PTG F2 proved to be significantly more resistant to cyclic fatigue than PTG F3</u> with higher mean of NCF and time to fracture. The same trend was verified when evaluating the relation among PTU F2 and PTU F3. These findings can be easily explained since resistance of rotary instruments to cyclic fatigue decreases when instrument sizes and respective diameter increases, on instruments of the same design (Fife *et al*. 2004; Ullman & Peters 2005; Wollcot *et al*. 2006; Plotino *et al*. 2009; Sheng *et al*. 2010; Pérez-Higueras *et al*. 2014; Capar *et al*. 2015).
- A significant statistical difference concerning length of fracture among PTG F2 (6,46 ± 0,70) and PTG F3 (6,5 ± 0,37) was not shown; the same happened for PTG F2 (6,46 ± 0,70) and PTU F2 (6,42 ± 0,73). However, significant statistical difference between PTG F3 (6, 50 ± 0, 40) and PTU F3 (6, 06 ± 0, 34) was found.

In previous studies, it has been reported that fracture occurred usually at the point of maximum flexure (Pruett *et al*. 1997; Plotino *et al*. 2009). The point of maximum flexure was at 5 mm from the tip in this experiment. The difference between the mean lengths of fracture to this value may be due to an inaccurate measurement since a ruler was used. The use of an X-Y coordinates measuring table, for example, would be more accurate.

Nevertheless, recently Capar *et al*. showed that different instruments subjected to the same cyclic fatigue testing setup (same working length) fractured at different working lengths. The researchers attributed their results to differences in the bending moments of the instruments, which were manufactured from different alloys (Capar *et al*. 2015). Furthermore, a system designed to simulate a root canal that doesn't constrain a precise trajectory may alter bending properties of different files, even if they have the same dimensions (Plotino *et al*. 2009). A previous study has shown that if the artificial canal does not sufficiently restrict the instrument shaft, it would tend to spring back into its original straight shape, aligning into a trajectory of greater radius and reduced angle (Larsen *et al*., 2009). Gutmann & Gao 2012 discussed this limitation of cyclic fatigue testing in steel canals as well.

- PTG F2 and F3 proved to be significantly more resistant to cyclic fatigue than PTU F2 and F3, respectively. Despite the identical architecture and operation of the PTG and PTU systems, the different manufacturing processes of the instruments clearly affect their fatigue resistance behaviors. Several authors state that a higher proportion of martensite (which is known to be more flexible than austenitic NiTi) and changes in the phase transformation behavior may be the reason (Hayashi *et al*. 2007; Shen *et al*. 2011; Hieawy *et al*. 2015; Uygun *et al*. 2015). Moreover, CM-Wire® was proven to be significantly more resistant to fatigue than instruments produced using traditional NiTi (Plotino *et al*. 2012; Shen *et al*. 2012).

Data obtained from Vaz 2014 during *in vitro* studies concerning cyclic resistance of ProTaper Next^{TM} system was also used to compare the variable time to fracture among PTG F2 / PTN X2 and PTG F3 / PTN X3 instruments. This particular study was underlined under exactly the same conditions, with the same experimental assembly and procedure, which decreased the number of variables, ergo less bias. Regarding this comparison:

- The mean time to fracture for PTG F2 (109, 82 ± 23, 03) was significantly higher than time to fracture for PTN X2 (77, 8 ± 9, 3). . Beyond that, time to fracture for PTN X2 was significantly higher than time to fracture for PTU F2 (56,70 ± 6,78) (p<0,001).These results are in agreement with Uygun *et al*. study that showed higher values for cyclic fatigue for PTG instruments.

Different characteristics could be responsible for these findings; for example a different NiTi alloy composition and different cross section's geometry. PTG are manufactured with CM-Wire® technology and triangular cross section's; PTN of M-Wire®, with off-centered rectangular cross-section (Pérez-Higueras *et al*. 2014; Uygun *et al*. 2015). Plotino *et al*. stated that within instruments produced using CM-Wire®, a higher cyclic fatigue was present when comparing with M-wire® and conventional alloys as previously mentioned (Plotino *et al*. 2012).

Moreover, it has been shown that cross-sectional design has an impact on the stress developed by an instrument under either tension or bending (Zhang *et al*. 2010; Pérez-Higueras *et al*. 2014). A triangular cross-sectional design, present in PTG and PTU systems, was showed to possess a higher cyclic fatigue resistance than a square cross-sectional design (Cheung *et al*. 2011). This difference is related to the reduced metal mass of the instruments with a triangular cross-section compared with instruments with a square cross section of a similar diameter (Wu & Wesselink 1993; Capar *et al*. 2015; Uygun *et al*. 2015).

- <u>Time to fracture of PTG F3 (58, 18 ± 17, 01) was significantly lower than time to fracture for PTN X3 (89, 3 ± 9, 5).</u> Yet, different mean lengths of fracture were comprised between the two types of instruments. Fracture length data of X3 (4.5 ± 0.5) was much lower in relation to PTG F3 data (6.5 ± 0.37). That way, the local where the fracture occurred for PTN F3 had a smaller diameter. As mentioned above in the text, a larger diameter at the point of fracture will lead to a shorter time to fracture which can explain the reduced cyclic fatigue observed for PTG F3.

On the other hand, Uygan *et al*. noted that despite PTG had higher values for cyclic fatigue at all levels when comparing with PTN, when cyclic fatigue tests were performed at a distance equal to 8 mm from the tip, a point were the diameter between both instruments is similar, the difference was not significant.

That being noted, and taking to account that experimental data obtained with PTN X3 group in Vaz 2014 involved a small sample (n = 4), a possible conclusion is compromised.

To add, in order to compare data gathered in this study with current literature on the same subject, Table 6 summarize the type of instruments, testing conditions such as rotational speed and respective results on NCF and time to fracture.

	Article	Type of instrument	Testing conditions	Rotacional speed (rpm)	NCF (mean/st.dev)	Time to Fracture (mean/st.dev)
Protaper Gold^{RM}	present study	F2 F3	4,7 mm of radius 45˚ Dry conditions	300	549,08 ± 115,14 294,46 ± 87,97	109,82 ± 23,03 58,18 ± 17,01
	Uygun *et al.*, 2015	F2 (5 mm from the tip) F2 (8 mm from the tip)	3 mm of radius 60˚ Oil of lubrification	300	--	12219 67 ± 2089 44 3904 50 ± 520 63
	Hiewy *et al.*, 2015	F2 F3	6 mm of radius 40˚ Deionized water	300	985,2 ± 135,5 835,5 ± 119,3	--

Table 6 – Summary conditions, design and results of two studies made for PTG cyclic fatigue testing.

Even within the same file system major differences can be noticed respecting NCF and time to fracture data among different studies.

The variable results can be attributed to significant details that differ among the experimental methods. Some of these factors include:

A. Radius of curvature

An increase on radius of curvature was proven to decrease time to fracture (Tripi *et al*. 2006; Inan *et al*. 2007; Kim *et al*. 2010).

Uygun *et al*. used a lower value of radius, which, according to literature, could lead to a higher time to fracture. On the other hand, Hiewy *et al*. had a higher value in this parameter and still the NCF values were higher. Thus, other variables must be taken to account.

B. Angle of curvature

Several studies showed that an increase in angle of curvature was found to decrease fracture time (Ullman & Peters 2005; JR *et al*. 2007; Wan *et al*. 2011).

In both studies used for this comparison, this value was higher.

C. Lubrification

Pilot experiments had indicated that lubrication with various agents did not result directly in different cyclic fatigue scores but helped to reduce heat generated, leading to a higher fatigue life (Ullman & Peters 2005; Shen *et al*. 2012). Moreover, Shen *et al*. showed that cyclic fatigue of CM-Wire® instruments is longer in liquid media than in air.

Taking this into account, a plausible explanation for such lower values in the present study may be due to the dry conditions used, with absence of lubrification along the tests carried out. In Uygun *et al*. and Hieawy *et al*., a lubrificating oil or liquid media was used.

Moreover, environmental conditions have shown to significantly affect the fatigue behavior of NiTi rotary instruments and fatigue tests should be carried out in similar environmental conditions, as suggested by Plotino *et al*. and Shen *et al*.

Some more limitations can be noticed in the present study as far it concerns testing cyclic fatigue of rotary instruments.

For example, to date, there is no specification or international standard to test cyclic fatigue resistance of endodontic rotary instruments. Such a new standard is required in order to minimize uncontrolled variables, and to define suitable mechanical properties of NiTi rotary instruments for a safe, efficient clinical use and to introduce universally accepted testing devices for experimental evaluation of products or prototypes. In addition, a consensus between researchers should also be reached to find the most accurate statistical analysis (Plotino *et al*. 2009).

It has been also reported that static cyclic fatigue tests (with no axial movement) showed lower results when compared with dynamic tests in which endodontic instruments are subjected to axial movements, even though it minimizes the effect of variables. Moreover, the instrument is generally tested beyond the time that the instrument is expected to be active at a specific level when shaping a root canal normally in the clinic. Therefore, higher cyclic fatigue resistance is expected in a clinical situation in which instruments are operated in a constant in and out motion that helps to avoid taper lock (Pérez-Higueras *et al*. 2014).

Beyond that, stainless steel canals do not exhibit similar properties to those of root canals found in real teeth. It is possible that instruments may perform in a different manner when used clinically (Wan *et al*. 2011).

VI. Conclusion

Some challenges can be found during root canal preparation, like complex anatomy of the root canal system and instrumental limitations inherent to treatment.

An increasing concern about instrument fracture during clinical procedure urges since NiTi rotary instruments have been gaining popularity in endodontic treatment. Several authors advocate that the great majority of instruments appeared to have failed because of cyclic fatigue. Therefore, understanding cyclic fatigue of different endodontic instruments may be a subject of interest.

The purpose of this study was to characterize the cyclic fatigue of Protaper Gold^{RM} instruments, and compare it to other rotary systems.

Regarding Protaper Gold^{RM} system, F2 instrument showed superior cyclic fatigue resistance when compared with F3. More, comparing data from PTG F2 and F3 with ProTaper® Universal F2 and F3, respectively, ProTaper Gold^{RM} showed a superior behavior on cyclic fatigue resistance, with higher time to fracture (PTG F2 > PTGF3 ≥ PTU F2 > PTU F3).

When comparing data from this study with and analogue that undergone the same testing conditions and assembly line from ProTaper Next™ system, PTG F2 instrument proved to have a higher time to fracture over PTN X2, hence a better cyclic fatigue performance (PTG F2 > PTN X2 > PTU F2).

To date, there's no specification or international standard to test cyclic fatigue resistance of endodontic rotary instruments. Thus, different results may arise.

That being stated, it is important for clinicians to understand the differences between systems of files to take advantage of the latest technology and facilitate good choices to meet anatomic challenges.

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APPENDIX

Abbreviations

CNC - Computerized Numerical Control
CM - Control Memory
D - Diameter
M - Memory
NCF - Number of Cycles to Fracture
NiTi - Nickel-Titanium
PTG - ProTaper Gold
PTN - ProTaper Next
PTU - ProTaper Universal
TTR - Transformation Temperature Range
K-S – Kolmogorov-Smirnov

Symbols

% - percentage
n - number of sample
p - significance
® - registered trademark
RM – reference model
TM - unregistered trademark

Units

º - degrees
ºC - degree Celsius
sec - seconds
mm - millimeters
N. cm - newton centimeter
rpm – rotations per minute